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Notes on the SpaceX Starlink VHF Beacon Satellites

Introduction

In early 2023, I noticed increased activity on 137.055 MHz which did not match with any SpaceBEEs operating on this frequency [9]. These unknowns had the similar LoRa characteristics of a SpaceBEE 87-byte beacon packet.

By loading Orbiton 3.71 tracking software with TLEs for all the LEO launches for 2023, it became clear that these unknowns were Starlink spacecraft. A Google search revealed the connection between Swarm, SpaceX and Starlink spacecraft with VHF Tracking Beacons. See **Background** below.

Data

The VHF tracking beacon packets are received using LoRa parameters of sync word 12 hex, Bandwidth 41667 Hz, Spreading Factor 8 on 137.055 MHz, has 87 bytes and is typically transmitted every 40 seconds.

The preliminary beacon packet format has a 17-byte header, a 20 bytes Ephemeris data segment, 21-byte Telemetry A data segment and 29 bytes Telemetry B data segment. This format is subject to change after further analysis. The data are formatted "little endian".

Header segment

- Message Number 3 byte, increments by one with each message.
- Spacecraft Number 2 bytes, 07XX_{hex}, 08XX_{hex}, 09XX_{hex} and 0AXX_{hex} seen so far.
- Packet Type 1 byte, CC_{hex} = 87 byte packet
- Semi-fixed 7 bytes, To Be Determined (TBD)
- UTC Time Code 4-byte, 32-bit unsigned integer timecode, seconds since 1/1/1970.

Ephemeris segment

- Latitude 4 byte, 32-bit single precision floating point, decimal degrees, +N, -S
- Longitude 4 byte, 32-bit single precision floating point, decimal degrees, +E, -W
- Altitude 4-byte, 32 bit unsigned integer, Metres above datum
- Semi-fixed TBD 8 byte, probably 4 16-bit signed integer values

If Ephemeris data is not available, this segment is filled with zeros.

Telemetry A segment

- TBD 15 bytes
- GPS Week Number 2 byte eg. 08d4_{hex} = 2260 = 1024+1024+212
- GPS Centi-Seconds 4 bytes eg. 0309bac0_{hex} = 509692.80 seconds

Telemetry B segment

- TBD 29 bytes

If Telemetry B data is not available, the segment is filled with zeros.

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Segment	Parameters	Bytes	Data in little endian	Value
Header 17 bytes	Message Number	3	ae803e	4096174
	Spacecraft ID	2	5109	2385
	Packet Type	1	cc	
	Semi-fixed	7	0000d0 eb4e4b03	
	UTC Timecode	4	6d765564	5 May 2023 21:34:37
Ephemeris 20 bytes	Latitude	4	313d06c2	-31.5597572 °
	Longitude	4	62100f43	143.064 °
	Altitude	4	19530600	414489 metres
	Semi-fixed TBD	8	0000 98a3 1400 0430	
Telemetry A 21 bytes	Semi-fixed TBD	15	90fc21ba 04030000 82ca660e 060800	
	GPS Week	2	d408	2260
	GPS Week Seconds	4	c0ba0903	5 May 2023 21:34:34
Telemetry B 29 bytes	Semi-fixed TBD	29	8b601e58 f2f4b148 1d8bce93 eb3fcff2b 74f6ff674 afbff1e10 d2dc07	

Sample Data

137.055 MHz 5 May 2023 UTC

2023-056 launch

21:34:36

ae803e5109cc0000d0eb4e4b036d765564313d06c262100f4319530600000098a31400043090fc21ba0403000082ca660e060800d408c0ba090318b601e58f2f4b1481d8bce93eb3fcff2b74f6ff674afbff1e10d2dc07

21:35:20

36803e3a09cc0000d02dd74b0399765564a3210fc2291314432c560600000d0a21400032f9afc20a604030000825a680e060800d408efcb0903130c17e4d9b163111c7e72e82248fdffa805f6ff7bd9fbff2ad50cf90a

21:36:00

8c823ee309cc0000d0780b4b03c2765564d96a25c21c3d1043cc960600000389a14000430a4fc219c0403000082ca660e060800d408b7db0903f5f03de736a5d411d51b50e52c3bf8ff5a4ff8ff43110200c21a4d390c

21:36:16

af803e5109cc0000d038574b03d1765564b6f411c2e6ae154388570600000d0a21400043090fc340a00030020822e670e060800d408d0e109032b62dde30fb4731032500be83674fdffdee5f5ff120cfcffde51e82408

21:36:18

94803e5309cc0000d054294b03d47655640eb00fc2a030144308570600000d0a21400032f9afc20ba0403000082be680e060000d408d4e20903b75f1ae485bb4d1180f65de8d147fdfff201f6ff24e3fbff0e9724e90b

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Background

In May 2020, SpaceX made an application to USA Federal Communication Commission (FCC) to launch a 30,000 Second Generation Starlink satellite constellation. [1]

In July 2021, SpaceX acquired Swarm Technologies which had developed and launched an “Internet of Things” IOT satellite network based on the 1/4U SpaceBee satellite and LoRa communication protocol using the VHF Band (137-138 MHz downlink, 148-150 MHz uplink). [2]

In December 2022, SpaceX amended their May 2020 Gen2 application to add VHF TT&C Beacons. [3]

Also in December 2022, the USA Federal Communication Commission authorised SpaceX to build and launch their Second generation of the Starlink constellation but denied the use of a “VHF beacons”. [4]

In response, SpaceX requested Special Temporary Authority (STA) to use VHF beacons for 60 days for upcoming launches. [5]

The FCC granted the STA on 17 Feb 2023. [6]

References:

1. [SAT-LOA-20200526-00055](#)
2. [SpaceNEWS](#)
3. [SAT-AMD-20221216-00175](#)
4. [FCC-22-91](#)
5. [SAT-STA-20221215-00174](#)
6. [FCC DA-23-145](#)
<https://docs.fcc.gov/public/attachments/DA-23-145A1.pdf>
7. List of Starlink and Starshield launches, Wikipedia
https://en.wikipedia.org/wiki/List_of_Starlink_and_Starshield_launches
8. Starlink Statistics. Jonathan's Space Pages.
<https://planet4589.org/space/con/star/stats.html>
9. “Notes on the Swarm SpaceBEE Satellites”. Mike Kenny 2022
<http://members.iinet.net.au/~mdkenny@netspace.net.au/SpaceBEE.pdf>

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Starlink launches in 2023

Launch Number	Date	Catalog Number	Number	Height, kms	Inclination, °
67	28/12/22	2022-177	54	530	43.0
68	19/1/23	2023-010	51	570	70.0
69	26/1/23	2033-013	56	530	43.0
70	31/1/23	2023-014	49	570	70.0
71	2/2/23	2023-015	53	530	43.0
72	12/2/23	2023-020	55	530	43.0
73	17/2/23	2023-021	51	570	70.0
74	27/2/23	2023-026	21	525	43.0
75	3/3/23	2023-028	51	570	70.0
76	17/3/23	2023-037	52	570	70.0
77	24/3/23	2023-042	56	530	43.0
78	29/3/23	2023-046	56	530	43.0
79	19/4/23	2023-056	21	525	43.0
80	27/4/23	2023-058	46	560	97.6
81	4/5/23	2023-061	56	530	43.0
82	10/5/23	2023-064	51	530	70.0
83	14/5/23	2023-065	56	530	43.0
84	19/5/23	2023-067	22	525	43.0
85					

Launch 67 is included as it was the first launch into a Starlink Gen2 43.0° orbit shell.

Reference: 7 and 8. https://en.wikipedia.org/wiki/List_of_Starlink_and_Starshield_launches